Estimation of Energy saving of Commercial building by living wall and green facade in Sub-tropical climate of Australia

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ABSTRACT
This paper investigates energy saving potential of commercial building by living wall and green façade system using Envelope Thermal Transfer Value (ETTV) equation in Sub-tropical climate of Australia. Energy saving of four commercial buildings was quantified by applying living wall and green façade system to the west facing wall. A field experimental facility, from which temperature data of living wall system was collected, was used to quantify wall temperatures and heat gain under controlled conditions. The experimental parameters were accumulated with extensive data of existing commercial building to quantify energy saving. Based on temperature data of living wall system comprised of Australian native plants, equivalent temperature of living wall system has been computed. Then, shading coefficient of plants in green façade system has been included in mathematical equation and in graphical analysis. To minimize the air-conditioned load of commercial building, therefore to minimize the heat gain of commercial building, an analysis of building heat gain reduction by living wall and green façade system has been performed. Overall, cooling energy performance of commercial building before and after living wall and green façade system application has been examined. The quantified energy saving showed that only living wall system on opaque part of west facing wall can save 8-13 % of cooling energy consumption where as only green façade system on opaque part of west facing wall can save 9.5-18% cooling energy consumption of commercial building. Again, green façade system on fenestration system on west facing wall can save 28-35 % of cooling energy consumption where as combination of both living wall on opaque part of west facing wall and green façade on fenestration system on west facing wall can save 35-40% cooling energy consumption of commercial building in sub-tropical climate of Australia.

Keywords: Energy saving, ETTV, Living wall, Green façade

1. INTRODUCTION

Buildings energy estimation is critically important to address climate change because of increased CO_2 emissions due to remarkable amount of energy consumption of building. Both homes and commercial building energy consumption are responsible for approximately 20 percent of Australia's greenhouse gas emissions and air-condition consumes nearly 21% of total commercial energy consumption within Australia (CIE, 2007; COAG, 2010). Commercial buildings heat gain depend on construction such as types of materials used, composition of glazing, orientation, shape of buildings, climate data such as solar radiation, ambient temperature, location etc. To reduce air conditioned load, it is necessary to reduce heat gain by wall and window of building. ETTV is a method to determine average heat gain of building through its envelope. Chua and Chou developed ETTV for Singapore from OTTV (Chua et al., 2010). ETTV is one of the simplest methods to determine heat gain of building (Chou et al., 1998). Another advantage of ETTV is, it can control building energy during design stage and can predict future energy demand for air-conditioning (Vijayalaxmi, 2010). Due to different climate zones, solar factor, orientation of buildings, indoor and outdoor temperature differences, it would be better to consider ETTV for sub-tropical climate zone of Australia as ETTV formerly named as OTTV has been studied in different climate zones of the world (Chua et al., 2011; Utama et al., 2011; Radhi, 2009; Lam et al., 2008; Yang et al., 2008; Praditsmanont et al., 2008; Chirarattananon et al., 2004; Chow et al., 1998). Living wall is a system of growing plants in a fixed structure on external or internal walls to reduce the wall temperature of building where as green façade is a system of growing plants potted on a ground or on a wire structure before the wall or before the fenestration system as a bio-shader to get the shading effect, therefore to reduce the solar heat gain. Green façade and Living wall are embryonic technologies that have been used to improve thermal performance of buildings (BEDP, 2008). Kenneth et al., studied the shading performance of vertical deciduous climbing plant canopy (Ip et al., 2010). However, cooling energy estimation of buildings in presence of deciduous plant in a green façade system was absent in his research. Again, Kontoleon and Eumorfopoulou analyzed the thermal performance of plant covered building wall (Kontoleon et al., 2010). But, the required air-conditioned load of building in presence of living wall system has not been discussed. Wong et al., used Nephrolepis exaltata (Boston fern) in vertical greenery system and indentified 50% of ETTV reduction is possible when the results were obtained in TAS simulation in Singapore (Wong et al., 2009). However, cooling energy performance in presence of vertical greenery has not been demonstrated in his study. In Australia, energy estimation of commercial building using ETTV with analysis of green façade and living wall system made of Australian native plant in sub-tropical climate has not been studied. In this present study, ETTV based energy estimation has been considered as a performance method for commercial building cooling energy consumption and the effect of living wall and green façade on commercial building cooling energy consumption has been analyzed within sub-tropical climate zone of Australia.

2. METHODOLOGY

Collected data relevant to existing commercial building envelope parameters with actual air-conditioned energy consumption and determination of ETTV value of those existing buildings in subtropical climate was the initial step of this study. In the first step, ETTV values have been calculated and predicted cooling energy consumption of existing commercial building was estimated by reliable mathematical model, Trane Trace 700 v6.2.6.5 and eQUEST v.3.64. Finally, the calculated value of cooling energy consumption has been compared with actual consumption. The next process was to collect temperature data of living wall system from an experimental setup comprised of Australian native plant including Bulbine vagans and Plectranthus argentatus, at the University of Queensland, UQ, Gatton, Australia. Living wall surface temperature, air gap temperature and internal wall temperature have been measured by YC7U4UD and Tiny Tag Plus 2 data logger with thermistor probe in every 30 minutes from the experimental facility. Then equivalent temperature value has been estimated by mathematical model to use this value in ETTV estimation and corresponding cooling energy estimation in presence of living wall. The third step was mathematical analysis of shading co-efficient of plants using solar radiation data in a green façade system comprised of deciduous plant suitable for sub-tropical climate of Australia. Then shading co-efficient value was used in ETTV estimation and corresponding cooling energy estimation in presence of green façade system. Finally, heat gain and cooling energy consumption before and after living wall and green façade application have been compared to estimate energy saving.

3. MATHEMATICAL MODEL

3.1 Commercial building heat gain and cooling energy consumption in absence of living wall and green façade system

As per Chua and Chou’s mathematical model for weighted averaged total building envelope heat gain and cooling energy consumption can be written as (Chua et al., 2010).

$$H_t = [TD_{eq}(1-WWR)U_{wa} + \Delta T(WWR)U_f + SF(WWR)(CF)(SC)] + Q_{int} \quad (1)$$

$$E_c = \gamma\ H_t * A_t * 24\ (D)\ (a)\ (b) / \Delta t\ (COP)^n \quad (2)$$

Equivalent temperature difference in the equation (1) can be written as (Lam, J.C. et al., 2008)

$$TD_{eq} = (T_{ao} - T_{ai}) + [\ \alpha \times R_{so} \times avg\ (I_t)\ ] \quad (3)$$

Where, total irradiation on vertical surface, I_t due to direct, diifuse and reflected radiation has been estimated based on the mathematical expression developed by Keller and Costa (Keller et al., 2008)

$$I_t = [Max\ (Cos\ \theta) + C*0.45 + Sin\beta*(1 - Cos\alpha_n)/2 + C]\ G_{nd} \quad (4)$$

3.2 Commercial building heat gain and cooling energy consumption in presence of only living wall system

Due to living wall in opaque part of west facing wall, the equation (3) for equivalent temperature difference would be

$$TD_{eqg} = (T_g - T_{ai}) + [\ \alpha \times R_{so} \times\ (I_t)\ ] \quad (5)$$

I_t will be zero for building wall due to presence of living wall in front of building wall,

$$TD_{eqg} = (T_g - T_{ai}) \quad (6)$$

Hence, the heat gain equation becomes for west facing wall in presence of living wall system

$$H_{lw} = TD_{eqg}\ (1\text{-}WWR)U_{wa} + \Delta T(WWR)U_f + SF(WWR)(CF)(SC) \quad (7)$$

If west facing wall is covered by living wall and other walls remain uncovered, the weighted average heat gain and cooling energy consumption would be

$$H_b = (H_{lw} \times A_w + H_n \times A_n + H_s \times A_s + H_e \times A_e)/\ (A_w + A_n + A_s + A_e) \quad (8)$$

$$E_{cw} = \gamma * A_t\ (H_b) * 24\ (D)\ (a)\ (b)/\ \Delta t\ (COP)^n \quad (9)$$

3.3 Commercial building heat gain and cooling energy consumption in presence of only green facade system

As per Monsi, the solar radiation before and behind the canopy (Monsi et al., 2005)

$$I_0/I_t = e(-^{K * LAI}) \quad (10)$$

As per Gao, the ratio of solar radiation before and behind the canopy can be written as (Gao, 1996),

$$E_{sc} = I_0/I_t \quad (11)$$

3.3.1 When green facade system is in front of west facing wall

So, the heat gain equation becomes for west facing oreintation

$$H_{gf1} = TD_{eq}(1\text{-}WWR)U_{wa} * E_{sc} + \Delta T(WWR)U_f + SF(WWR)(CF)(SC) \quad (12)$$

Here, E_{sc} acts as external shading multiplier for wall due to green facade system infront of wall as Devgon et al., formulated external shading multiplier which can be applied to window as well as wall if there is any shading effect externally outiside of the window or wall such as overhang, green facade etc. (Devgon et al., 2010)

If west facing wall is covered and other walls remain uncovered, then weighted average heat gain and cooling energy consumption would be

$$H_{b1} = (H_{gf1} \times A_w + H_n \times A_n + H_s \times A_s + H_e \times A_e)/\ (A_w + A_n + A_s + A_e) \quad (13)$$

$$E_{cf1} = \gamma * A_t\ (H_{b1}) * 24\ (D)\ (a)\ (b)/\ \Delta t\ (COP)^n \quad (14)$$

3.3.2. When green facade system is in front of west facing window

The basic concept of shading co-efficient of a fenestration system,

$$T_{sc} = SC_1 \times E_{sc} \quad (15)$$

So, the heat gain equation becomes for west facing orienation

$$H_{gf2} = TD_{eq}(1\text{-}WWR)U_{wa} + \Delta T(WWR)U_f + SF(WWR)(CF)(T_{sc}) \quad (16)$$

If green façade is in front of west facing fenestration and other fenestration of other orientations remain uncovered, then weighted average heat gain and cooling energy consumption would be

$$H_{b2} = (H_{gf2} \times A_w + H_n \times A_n + H_s \times A_s + H_e \times A_e)/\ (A_w + A_n + A_s + A_e) \quad (17)$$

$$E_{cf2} = \gamma * A_t\ (H_{b2}) * 24\ (D)\ (a)\ (b)/\ \Delta t\ (COP)^n \quad (18)$$

3.4 Commercial building heat gain and cooling energy consumption in presence of living wall on opaque part of west facing wall and green façade system on west facing fenestration (combination of both)

If living wall on opaque part of wall and green facade is in front of fenestration system, is placed in west facing wall

$$H_{lg} = TD_{eqg}(1\text{-}WWR)U_{wa}+\Delta T(WWR)U_f+SF(WWR)(CF)(T_{sc}) \quad (19)$$

If other walls remain uncovered, the weighted average heat gain and cooling energy consumption would be

$$H_{bo} = (H_{lg} \times A_w + H_n \times A_n + H_s \times A_s + H_e \times A_e)/ (A_w + A_n + A_s + A_e) \quad (20)$$

$$E_{cb} = \gamma * A_t \; (H_{bo}) * 24 \; (D) \; (a) \; (b)/ \Delta t \; (COP)^n \quad (21)$$

4. ANALYSIS

4.1 Analysis of Commercial buildings data for heat gain and cooling energy consumption in absence of living wall and green facade in sub-tropical climate of Australia

The total heat gain of building based on ETTV has been calculated by equation (1). ETTV is weighted average for four orientations (North, South, East or West). Equivalent temperature value of wall has been calculated based on equation (3) and solar factor values for vertical surface have been calculated based on equation (4). Mean outdoor temperature and average solar intensity for a specific location has been collected (for example, Latitude: 27.48° S, Longitude: 153.04° E) from website of Bureau of Mete orology (BOM), Australia (BOM, 2011) and compared with ASRDH handbook, (ASRDH, 2006) summarised in Table 1. All equivalent temperature value and solar factor values have been compared with AIRAH handbook for north, south, east and west orientation of building (AIRAH, 1994). The required cooling energy has been estimated based on equation (2) and has been compared with simulated value of standard software Trane Trace 700 v6.2.6.5 and eQUEST v.3.64. Then annual cooling energy consumption of commercial building based on ETTV has been compared with actual consumption for space cooling of commercial building and checked with standard value in AIRAH, 2007. A rectangular shaped model building simulated in eQUEST v.3.64 shown in Fig. 1.

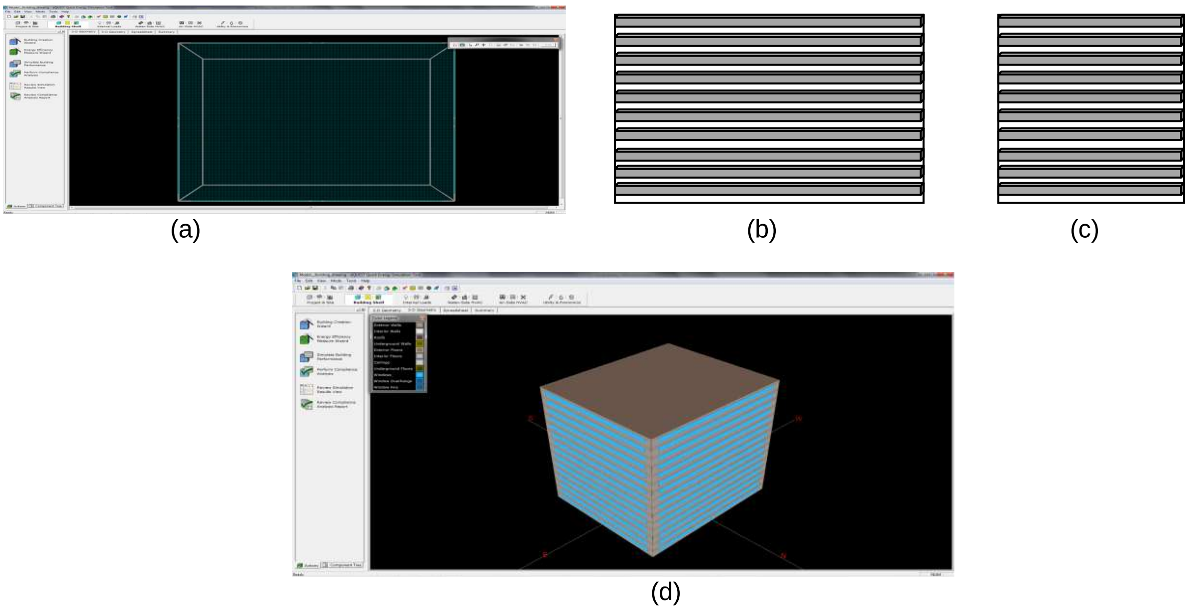


Fig. 1. (a) 2D plan view in eQUEST v.3.64 (b) North and South orientation (c) East and West orientation (d) 3D view of 10 storied rectangular shaped commercial building in eQUEST v.3.64

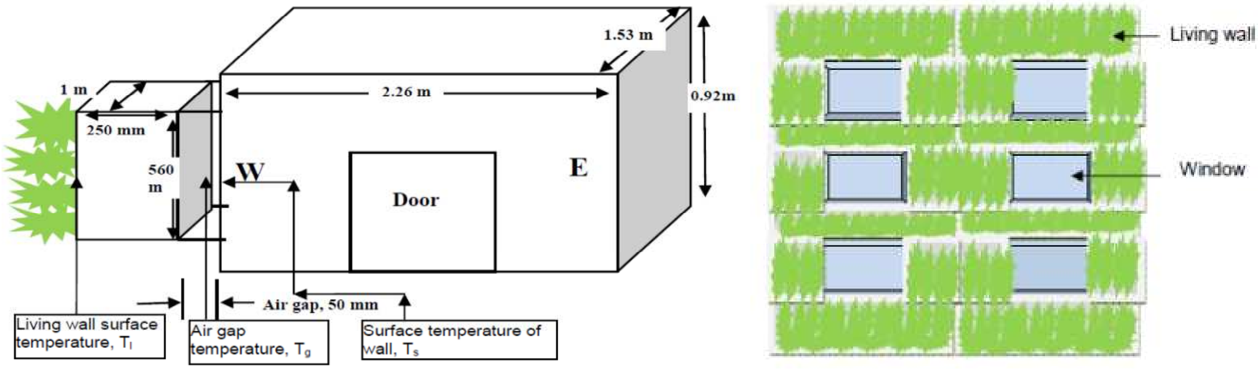
Table 1

Comparison of total irradiation on vertical surface

Orientation	Yearly (2006) average total radiation on vertical plane (W/m^2) based on available data from ASRDH , 2006 and Keller and Costa model (Keller et al, 2011)	Yearly (2010) average total radiation (W/m^2) on vertical plane based on BOM data and Keller and Costa model (Keller et al, 2011)
N	328	330
S	109	113
E	195	202
W	221	229

4.2 Analysis of commercial building heat gain and cooling energy consumption with effect of living wall

To anslyse the effect of living wall system of commercial building heat gain, an experimental setup of living wall system including plants Bulbine vagans and Plectranthus argentatus has been used in this analysis. Surface temperaute of living wall, T_l , Air gap temperature after living wall, T_g , and internal wall temperature of shed, T_s have been measured by YC7U4UD and Tiny Tag Plus 2 data logger with thermistor probe in every 30 minutes as shown in Fig. 2 (a). Then air gap temperature, T_g has been considered as outdoor ambient temperature of building wall with living wall system.



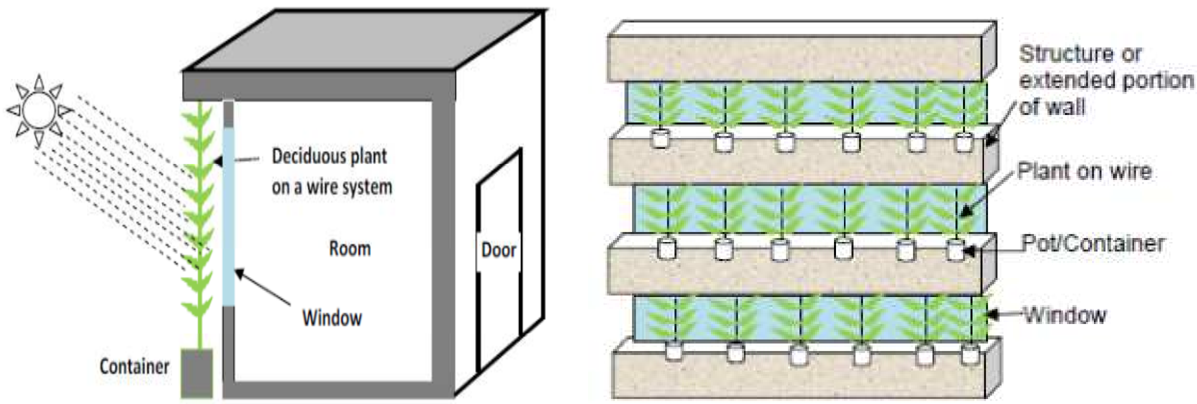
(a) (b)

Fig. 2 (a) Schematic diagram of experimental setup of Living wall system in west facing wall at the UQ, Gatton
(b) Living wall in opaque part of commercial building

All temperature data have been collected for 60 consecutive days to get more acurate and consisitent results. However, during analysis the temperature data in peak solar time between 9 am to 4 pm (local standard) has been considered. Equivalent temperature difference of building wall with living wall system has been computed by equation (6). So, the building heat gain estimated based on equation (8). Fig. 2 (a), showed the experimental facility used in this study and Fig. 2 (b) showed the application of living wall on mid rise commercial building.

4.3 Analysis of commercial building heat gain and cooling energy consumption with effect of green facade

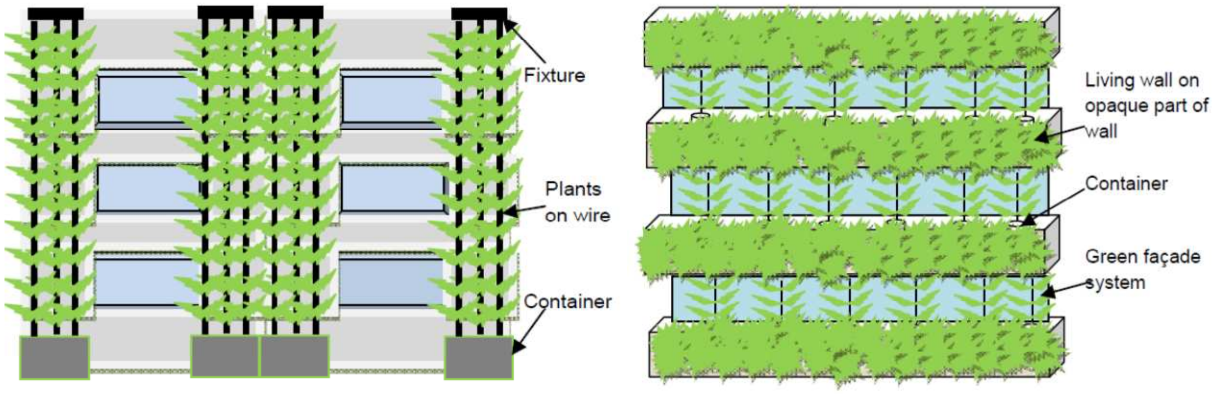
Brisbane rainforest action and information network (BRAIN), identified, Virginia creeper (Parthenocissus quinquefolia) as non smotherers ornamental species, presently used as ornamental puspose (BRAIN, 2000). Again, Maman and Barb identified Virginia Creeper as sub-tropical and temperate climbers (online article by Maman, 2011, Barb, 2011). Graeme Hopkins suggested Virginia creeper a prefereed species due to its no damage possibilty of building wall like other climbing ivy plants (Graeme et al., 2011).



(a) (b)

Fig. 3 (a) Green facade system in front of window with deciduous climbing plant
(b) Green facade system in front of fenestration of commercial building

Gabriel et al., measured the mean shading coefficient of plant Virginia creeper, a deciduous climbing plant gives the shading in summer and sheds off in winter, in a green facade system in Spain (Gabriel et al., 2010). Again, the value of light extinction coefficient, K and leaf area index, LAI were absent in Gabriel's analysis. The value of shading coefficient of Virginia creeper in Australian subtropical climate would not be same due to variation of solar intensity. To predict the shading co-efficient of Virginia creeper in Australian sub-tropical climate, the value of light extinction co-efficient K was considered 0.7 for Virginia creeper due to its horizontal leaves (Plants in action, UQ). David from Univeristy of Maryland, US identified that leaf area index of Virginia creeper was the highest after 350 days of planting which was 3.5 to 5 and the lowest during early stage of growth which was 1.5-1.9 (David, 2006).



(a) (b)

Fig. 4 (a) Green facade system in front of wall of commercial building
(b) Living wall on opaque part of wall and green facade before fenestration system (combination of both)

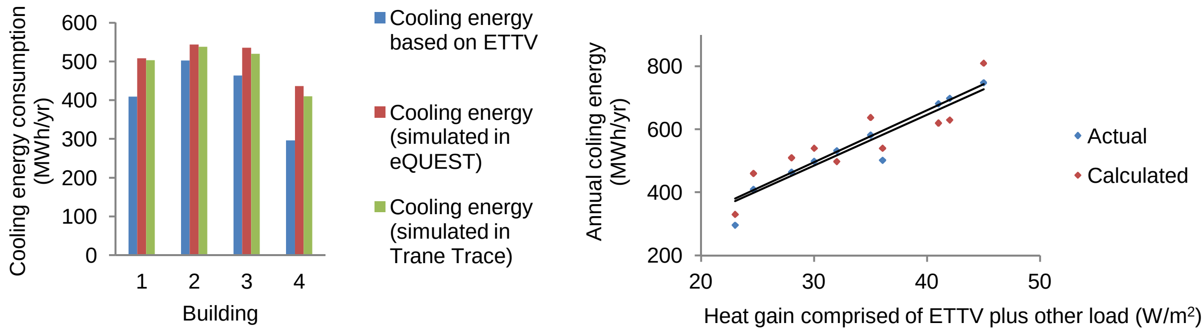
In this analysis, LAI of Virginia creeper has been varied from 1.5-5 assuming that LAI will be the highest after one year of planting.Then, the predicted incident radiation behind the Virginia creeper, I_0 in sub-tropical climate zone of Australia has been obtained from equation (10) using annual value of total irradiance on vertical surface, I_t . Finally shading coefficient of Virginia creeper for Australian subtropical climate has been obtained from equation (11) later used in equation (12) for heat gain calculation for green facade system infront of living wall. Again, by varying the value of different shading coefficeint of different glass, the total shading coefficient, T_{sc} has been obtained from equation (15) and later used in equation (17) for heat gain calculation in presence of green facade system in front of fenestration system. Fig. 3 and 4 showed different green facade system application on west facing wall.

Finally equation (9), (14), (18) and (21) have been used for cooling energy consumption in different cases for living wall and green facade system placed in west facing wall of commercial building.

5. RESULTS

5.1 Commercial building heat gain and cooling energy consumption in absence of living wall and green façade system in sub-tropical climate of Australia

The estimated cooling energy consumption based on ETTV has some deviations when it is compared with simulated cooling energy consumption in Trane Trace v6.2.6.5 and eQUEST v.3.64 as shown in Fig. 5.1(a) from case studied mid-rise (8-10 floors) commercial building of sub-tropical climate of Australia. From Fig. 5.1 (a), it has been observed that, ETTV value of these commercial building contributed 70%-80% of space cooling load.



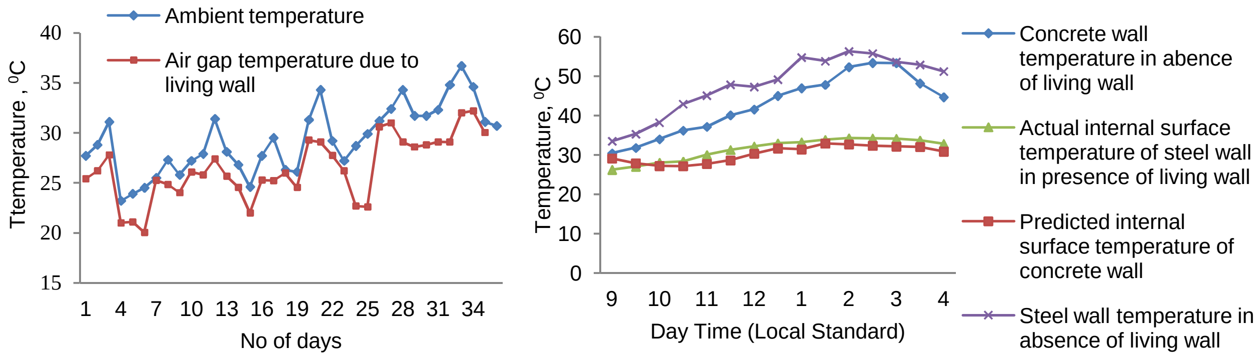
(a) (b)

Fig. 5.1 (a) Comparison of cooling energy estimation by ETTV and other standard software
(b) Comparison of cooling energy consumption based on ETTV and actual consumption

The remaining percentage comes from internal load such as equipment, lighting and miscellaneous load. However, if all heat gain due to envelope and internal gain were included in space cooling energy estimation, then the results showed 5 to 10 % deviation of actual consumption as shown in Fig. 5.1 (b) from the 10 case studied commercial building. So, it can be concluded that building envelope contributes significantly in heat gain of commercial building.

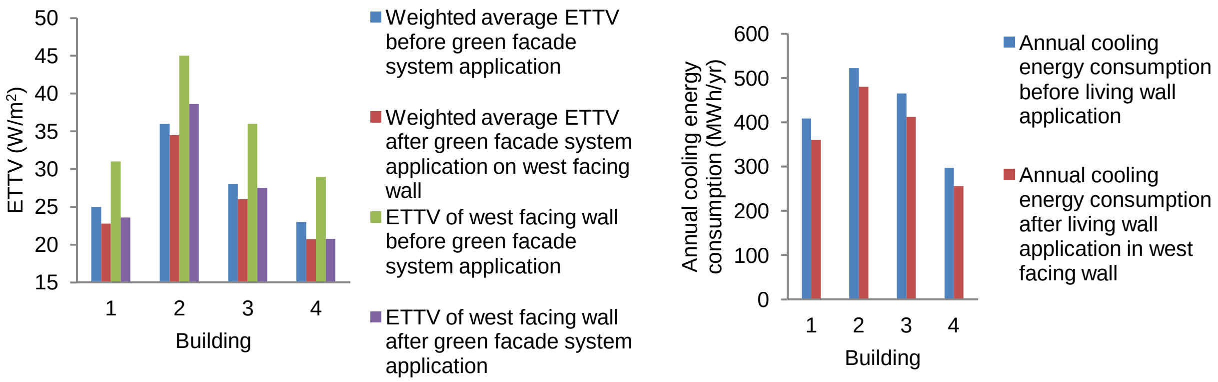
5.2 Commercial building heat gain and cooling energy consumption in presence of living wall in sub-tropical climate of Australia

Collected data of ambient temperature from nearest BOM and air gap temperature of living wall system have been plotted considering the peak air gap temperature between 9 am to 4 pm of 34 consecutive days in October to November 2011 from the experimental facility at the University of Queensland, Gatton. It has been observed that air gap temperature due to living wall system was 2.6 to 4 ^{0}C less than ambient temperature in an average during measurement as shown in Fig. 5.2 (a). As air gap temperature is less than ambient temperature, so it has a contribution to less equivalent temperature of building wall in presence of living wall. Again internal surface temperature of steel wall was always lower than steel wall without living wall system as shown in Fig. 5.2 (b). The predicted concrete wall temperature has been computed based on concrete wall surface temperature in absence of living wall system measured by infrared sensor and some mathematical modeling comparison with steel wall. So, living wall in opaque part of building wall reduces wall temperature which has an influence on ETTV of building wall. As the experimental setup was in west facing wall, so ETTV of west facing wall in four case studied building was found lower as demonstrated in Fig. 5.2 (c) and weighted average ETTV of four orientations was 8 to 10 % less compared to building without living wall system in west facing wall. So, the resultant annual cooling energy consumption was 8 to 13 % less compared to building without living wall system as shown in Fig. 5.2 (d).



(a) (b)

Fig. 5.2 (a) Peak temperature observed during measurement (b) Internal surface temperature of west wall

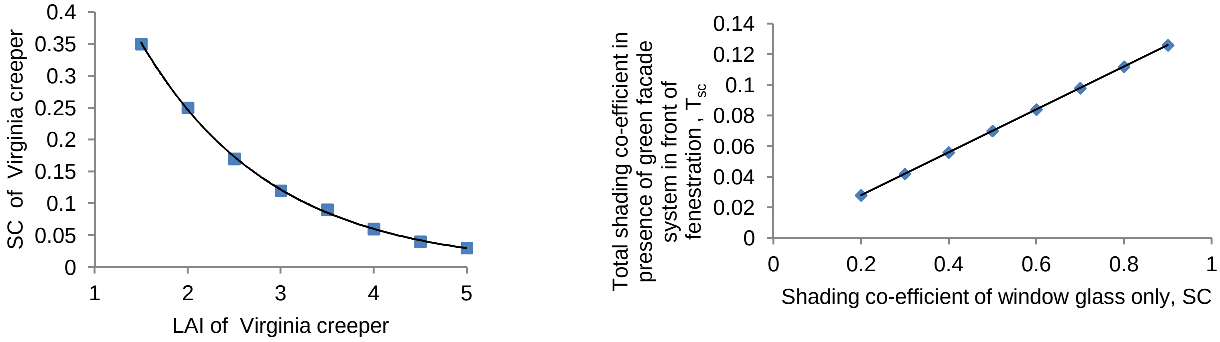


(c) (d)

Fig. 5.2 (c) Weighted average ETTV and ETTV of west facing wall in case studied building
(d) Annual cooling energy consumption before and after living wall application in west facing wall

5.3 Commercial building heat gain and cooling energy consumption in presence of green façade system in sub-tropical climate of Australia

The calculated total solar irradiation including direct and diffuse behind the Virginia creeper canopy in a green façade system have been used to determine the predicted shading co-efficient of Virginia creeper for sub-tropical climate of Australia. The relationship between shading co-efficient of Virginia creeper and LAI was found exponential. Shading co-efficient of Virginia creeper was the highest due to lowest LAI and lowest was due to the highest LAI as shown in Fig. 5.3 (a). However, the average value of shading co-efficient of Virginia creeper was 0.14 and it was considered during heat gain and cooling energy estimation. The total shading co-efficient value of fenestration system was lower as external shading co-efficient value due to Virginia creeper's shading co-efficient affect the total shading co-efficient as shown in Fig. 5.3 (b). The minimum total shading co-efficient value was found 0.028 for glass having shading co-efficient 0.2 and the maximum was found 0.12 for a glass having shading co-efficient 0.86. So, the total shading co-efficient of fenestration system was reduced in each case.

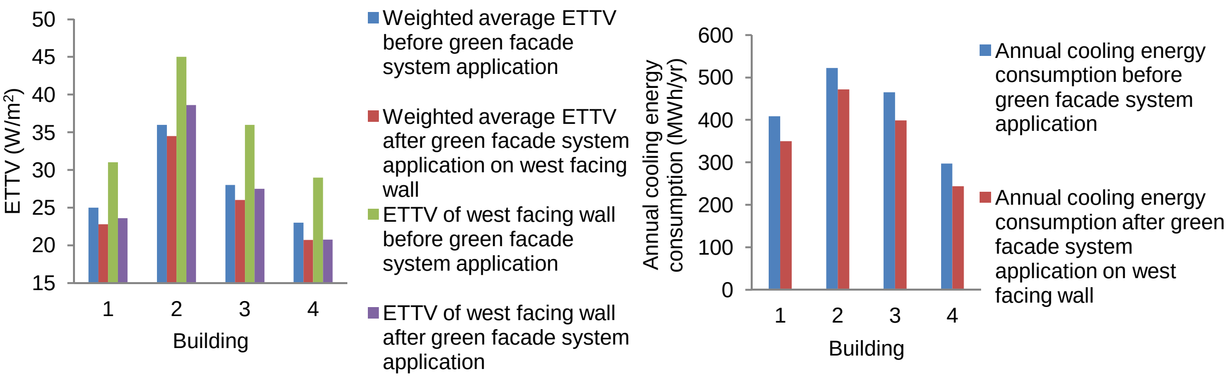


(a) (b)

Fig. 5.3 (a) Co-relation between LAI and SC of Virginia creeper in sub-tropical climate of Australia
(b) Predicted total shading co-efficient of fenestration system due to shading co-efficient of green façade system and shading co-efficient of glass

5.3.1 When green façade system is in front of west facing wall of commercial building

From Fig. 5.3 (c), it was depicted that weighted average ETTV was reduced due to green façade system on opaque part of west facing wall. The weighted average ETTV was reduced to 8-10 % in each case studied building.



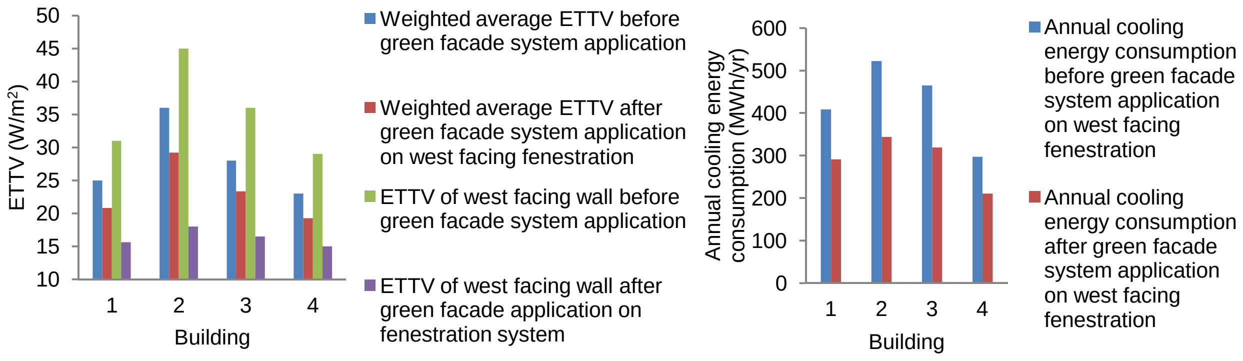
(c) (d)

Fig. 5.3 (c) Weighted average ETTV and ETTV of west facing wall due to green façade system
(d) Annual cooling energy consumption before and after green façade system application on west facing wall in case studied commercial building

Again, the reduction was significant in west facing wall and it was between 23-29 % in case studied building. Overall, the total annual cooling energy consumption of commercial building was reduced to 9.5-18 % due to green façade system application on west facing wall of case studied building as shown in Fig. 5.3 (d).

5.3.2 When green façade system is in front of west facing fenestration system of commercial building

From Fig. 5.3 (e), it was illustrated that weighted average ETTV was reduced due to green façade system on fenestration part of west facing wall. The weighted average ETTV was reduced to 16-18 % in each case studied building. However, the reduction was significant in west facing wall and it was between 48-60 % in case studied building. Overall, the total annual cooling energy consumption of commercial building was reduced to 28-35 % due to green façade system application on west facing wall of case studied building as shown in Fig. 5.3 (f).

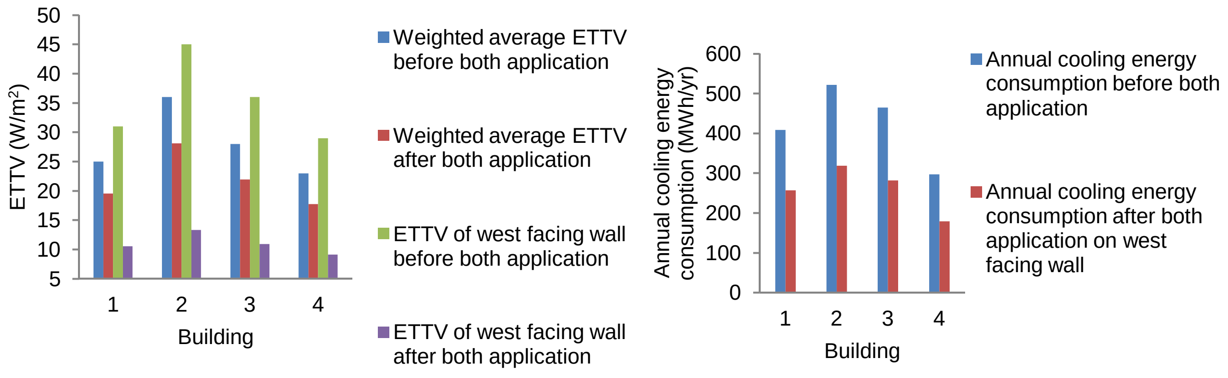


(e) (f)

Fig. 5.3 (e) Weighted average ETTV and ETTV of west facing wall due to green façade system on west facing fenestration (f) Annual cooling energy consumption before and after green façade system application on west facing fenestration in case studied commercial building

5.4 Commercial building heat gain and cooling energy consumption in presence of living wall system on opaque part of west facing wall and green façade system before fenestration in sub-tropical climate of Australia

From Fig. 5.4 (a), it was illustrated that weighted average ETTV was reduced due to living wall on opaque part of west facing wall and green façade on west facing fenestration (combination of both). The weighted average ETTV was reduced to 21-23 % in each case studied building. However, the reduction of ETTV was significant in west facing wall and it was between 65-70 % in case studied building. Overall, the total annual cooling energy consumption of commercial building was reduced to 37-40 % due to green façade system application on west facing wall of case studied building as shown in Fig. 5.4 (b).



(a) (b)

Fig. 5.4 (a) Weighted average ETTV and ETTV of west facing wall when living wall on opaque part of west facing wall and green façade on west facing fenestration (combination of both)
(b) Annual cooling energy consumption before and after living wall and green façade system on west facing orientation in case studied commercial building

6 DISCUSSIONS

In summary, only external living wall in opaque part of west facing wall can reduce 10-12 % cooling energy consumption of commercial building where as green facade system on opaque part of west facing wall can reduce

10-18 % of cooling energy consumption of commercial building. Again, green facade system in fenestration system of west facing wall can reduce 28-35 % cooling energy consumption of commercial building. However, the best results would be obtained from combination of living wall system in opaque part of west facing wall and green facade system in fenestration system made up of deciduous plant for west facing wall. This combination showed a reduction of 35-40 % of cooling energy consumption of commercial building. Recorded data from living wall setup may vary in different parts of Australia due to variations of solar radiation and weather condition. Again, accurate measurement of solar radiation using Pyranometer behind the canopy in a real commercial building application with analysis of summer, winter and spring condition would give a better prediction of cooling energy saving of commercial building application. Validated values of thermal conductivity of living wall system or green facade system will provide more accurate results for heat gain and corresponding cooling energy saving of commercial building. The results demonstrate the effectiveness of using a separate or a combination of living wall and green facade system application for cooling energy saving and reducing indoor air temperature in commercial building of Australia.

7 CONCLUSIONS

From the analysed results, it is evident that external living wall comprised of Australian native plants on opaque part of west facing wall and green facade system comprised of suitable plants for specific climate in opaque part or fenestration system of west facing wall of commercial building can reduce significant cooling energy consumption in sub-tropical climate of Australia. Depending on the type of living wall and green facade system application on west facing wall, the cooling energy saving would be minimum 10 % and maximum 40 %. The more significant savings can be obtained if living wall and green facade system is applied in other orientations of commercial building. Research on thermal conductivity of living walls and green facade system, and the application of green facade system on fenestration system through analysing of solar radiation needs to be investigated to establish more significant savings of cooling energy in the sub-tropical climate of Australia. A lot of research can be done regarding the maintenance cost of the application of living wall system and green facade system depending on their application suitability on different shapes of commercial building. Building designers, owners and operators should consider all of these factors into an effective sustainable technology plan for green building and making the use of this type of green and clean energy to reduce the CO_2 emissions which is a major concern in changing climate of global context.

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NOMENCLATURE

a	operating hours of a day for air-conditioning
b	operating days in a week for air-conditioning
A_t	total building envelope area (m^2)
A_s	area of south facing wall (m^2)
A_e	area of east facing wall (m^2)
A_n	area of north facing wall (m^2)
A_w	area of west facing wall (m^2)
B	atmospheric extinction coefficient
C	ratio of diffuse radiation on a horizontal surface to direct normal irradiation
CF	solar correction factor for fenestration
COP	coefficient of performance of Chiller at design point
D	number of cooling degree days
E_c	annual cooling energy consumption (MWh/yr)
E_{cw}	annual cooling energy consumption in presence of living wall system on west facing wall (MWh/yr)
E_{cf1}	annual cooling energy consumption when green facade system is in front of west facing wall (MWh/yr)
E_{cf2}	annual cooling energy consumption when green facade system is in front of window (MWh/yr)
E_{cb}	annual cooling energy consumption when both system is present (MWh/yr)
E_{sc}	effective shading coefficient of external shading devices (in this case plant)
G_{nd}	normal direct irradiation respectively, $G_{nd} = A*C_n/(e^B/\sin\beta)$ (W/m^2), where C_n is clearness number
H_{gf1}	heat gain due to green facade system on west facing wall (W/m^2)
H_{gf2}	heat gain due to green facade system on west facing window (W/m^2)
H_b	weighted average heat gain of building due to living wall system on west wall (W/m^2)
H_{b1}	weighted average heat gain of building due to green facade system on west wall (W/m^2)
H_{b2}	weighted average heat gain of building due to green facade system on west facing fenestration (W/m^2)
H_{bo}	weighted average heat gain of buildinf due to presence of both system in west facing wall (W/m^2)
H_n	heat gain by north facing of wall (W/m^2)

H_s heat gain by south facing wall (W/m^2)
H_e heat gain by east facing wall (W/m^2)
H_{lg} heat gain due to living wall system on west wall and green facade system on west facing window (W/m^2)
H_{lw} heat gain of west facing wall due to living wall system (W/m^2)
H_t total heat gain of building (W/m^2)
I_0 solar intensity behind canopy (W/m^2)
I_t average total irradiance on vertical surface (W/m^2)
K light extinction co-efficient
LAI leaf area index of plant
n correction factor in the part load performance of Chiller
Q_{int} internal heat gain due to occupants, lighting and equipment (W/m^2)
R_{so} surface flim resistance equivalent to 0.044 m^{2}K/W
SC shading coefficient of fenestration
SF solar factor (W/m^2)
T_{ai} design indoor air temperature 21^{0}C,
T_{ao} monthly mean outdoor temperature (^{0}C)
T_g air gap temperature due to living wall system (^{0}C)
TD_{eq}, equivalent temperature difference (^{0}C) for opaque wall
TD_{eqg} equivalent temperature difference (^{0}C) for opaque wall in presence of living wall
T_{sc} total shading co-efficient due to window glass and deciduous plants infront of window
ΔT temperature difference between outdoor and indoor condition for window (^{0}C)
U_{wa} thermal transmittance of wall (W/m^{2}K)
U_f thermal transmittance of fenestration (W/m^{2}K)
WWR window to wall ratio
α absorption coefficient of wall
α_n tilt angle between the normal of the horizontal surface and the normal of the tilted surface
β solar altitude angle
γ linear function $\gamma = C\, Q_d / H_t\, A_t$, where C is a load factor, Q_d is design space cooling load
θ angle of incidence radiation

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